

04-25-01 Rec'd POT/PTO 24 APR 2001

FORM PTO-1390 (Modified) (REV 10-95)		U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE	ATTORNEY'S DOCKET NUMBER 013/02197
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371			U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 09/830374 ✓
INTERNATIONAL APPLICATION NO. PCT/IL98/00519 ✓	INTERNATIONAL FILING DATE October 25, 1998 ✓	PRIORITY DATE CLAIMED	

INVENTION  
DRIVER FOR PIEZOELECTRIC MOTORS ✓

APPLICANT(S) FOR DO/EO/US  
Shmuel BEN-YAAKOV

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
  - a. ☒ is transmitted herewith (required only if not transmitted by the International Bureau).
  - b. ☒ has been transmitted by the International Bureau.
  - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
  - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
  - b. ☐ have been transmitted by the International Bureau.
  - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
  - d. ☐ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 18 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.  
A **SECOND** or **SUBSEQUENT** preliminary amendment.
16. ☐ A substitute specification.
17. ☐ A change of power of attorney and/or address letter.
18. ☐ Certificate of Mailing by Express Mail
19. ☒ Other items or information:

Amendments to the International Application under PCT Article 34 are transmitted herewith as annexes to the IPER.

U.S. APPLICATION NO. (IF KNOWN) SEE 37 CFR 1.53 <b>09/830374</b>	INTERNATIONAL APPLICATION NO. <b>PCT/IL98/00519</b>	ATTORNEY'S DOCKET NUMBER <b>013/02197</b>
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20. The following fees are submitted:				<b>CALCULATIONS PTO USE ONLY</b>	
<b>BASIC NATIONAL FEE ( 37 CFR 1.492 (a) (1) - (5)) :</b>					
<input checked="" type="checkbox"/> Search Report has been prepared by the EPO or JPO .....		<del>\$930.00</del>			
<input type="checkbox"/> International preliminary examination fee paid to USPTO (37 CFR 1.482) .....		<b>\$720.00</b>			
<input type="checkbox"/> No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) .....		<b>\$790.00</b>			
<input type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO .....		<b>\$1,070.00</b>			
<input type="checkbox"/> International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) .....		<b>\$98.00</b>			
<b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>				<b>\$860.00</b>	
Surcharge of <b>\$130.00</b> for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).				<b>\$0.00</b>	
<b>CLAIMS</b>	<b>NUMBER FILED</b>	<b>NUMBER EXTRA</b>	<b>RATE</b>		
Total claims	45 - 20 =	25	x \$18.00	<b>\$450.00</b>	
Independent claims	3 - 3 =	0	x \$80.00	<b>\$0.00</b>	
Multiple Dependent Claims (check if applicable). <input type="checkbox"/>				<b>\$0.00</b>	
<b>TOTAL OF ABOVE CALCULATIONS =</b>				<b>\$1,310.00</b>	
Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) (check if applicable). <input checked="" type="checkbox"/>				<b>\$655.00</b>	
<b>SUBTOTAL =</b>				<b>\$655.00</b>	
Processing fee of <b>\$130.00</b> for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492 (f)).				<b>\$0.00</b>	
<b>TOTAL NATIONAL FEE =</b>				<b>\$655.00</b>	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable). <input type="checkbox"/>				<b>\$0.00</b>	
<b>TOTAL FEES ENCLOSED =</b>				<b>\$655.00</b>	
				<b>Amount to be refunded</b>	\$
				<b>charged</b>	\$


☐ A check in the amount of \_\_\_\_\_ to cover the above fees is enclosed.

☒ Please charge my Deposit Account No. **03-3419** in the amount of **\$655.00** to cover the above fees.  
A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **03-3419** A duplicate copy of this sheet is enclosed.

**NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.**

**SEND ALL CORRESPONDENCE TO:**

<b>William H. Dippert, Esq.</b> <b>Cowan, Liebowitz &amp; Latman, P.C.</b> <b>1133 Avenue of the Americas</b> <b>New York, NY 10036-6799</b> <b>USA</b>  <b>Tel.: (212) 790-9200</b>	 SIGNATURE  <b>Paul FENSTER</b> NAME  <b>33,877</b> REGISTRATION NUMBER  <b>April 22, 2001</b> DATE
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013/02197 A01

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

Applicant: S. BEN-YAAKOV  
 Serial Number: Not Yet Assigned  
 Filed: 25 October 1998 as PCT/IL98/00519 and Herewith as US National Stage  
 For: DRIVER FOR PIEZOELECTRIC MOTORS  
 Art Unit: Not Yet Assigned  
 Examiner: Not Yet Assigned

Honorable Commissioner of Patents and Trademarks  
 Washington DC 20231

**PRELIMINARY AMENDMENT**

Sir:

Further to the concurrent filing of the U.S. national stage of PCT/IL98/00519 kindly amend the application as follows prior to examination:

**IN THE SPECIFICATION**

Kindly add the following section, on page 1, immediately after the title:

**--RELATED APPLICATIONS**

The present application is a US national application of PCT/IL98/00519, filed 25 October 1998.--

**IN THE CLAIMS**

Kindly amend claims 1, 4, 6, 7, 9, 13-15, 18, 20, 21, 33, 36, 38-40, 43 and 45 in accordance with the following clean claims and add the following new claims 46 and 47.

Kindly cancel claims 3 and 12.

1. (Amended) A micromotor comprising:

a piezoelectric element having a common electrode and a plurality of other electrodes, including at least a first and a second electrode group, formed thereon, and , each group including at least one electrode;

a voltage source that produces a time varying voltage between first and second terminals thereof, said first terminal being connected to the common electrode and said second electrode being connected to a low voltage;

a switching arrangement having at least one first switch connected between said first group of electrodes and the second terminal of the power supply and a having at least one second switch connected between said second group of electrodes and the common electrode; and

a controller that selectively energizes the switches to selectively connect either the first or the second group of electrodes to the second terminal, said selective connection causing selective motion either a first direction or in an opposite second direction.

4. (Amended) A micromotor according to claim 1 wherein the piezoelectric element comprises a rectangular piezoelectric plate having first and second faces wherein the common electrode is formed on the first face and the first and second groups of electrodes are formed on the second face.

6. (Amended) A micromotor according to claim 1 wherein the micromotor comprises a motive surface and wherein motion is induced in a surface of a workpiece pressed against the motive surface when the piezoelectric element is electrified as aforesaid.

7. (Amended) A micromotor comprising:

an ultrasonically vibrating element; and

a drive circuit comprising:

an oscillating voltage source having a high voltage side connected to and electrifying at least one electrode of said ultrasonically vibrating element to cause a mechanical displacement of a portion thereof; and

a discrete switch arrangement attached to at least one additional electrode of said ultrasonically vibrating element to which said oscillating voltage is not connected which switch arrangement selects the direction of said displacement.

9. (Amended) A micromotor according to claim 7 , wherein:

the at least one additional electrode comprises a plurality of electrodes applied to a first face of said vibrating element; and

the at least one electrode comprises a common electrode applied to a second face of said element.

13. (Amended) A micromotor according to claim 1 wherein said switches of said switching arrangement are solid state switches.

14. (Amended) A micromotor according to claim 13 wherein said switches of said switching arrangement comprise transistorized switches.

15. (Amended) A micromotor according to claim 14 wherein said switches of said switching arrangement are Mosfet transistors.

18. (Amended) A micromotor according to claim 16 and including a pair of diodes, one of which is connected across each said Mosfet transistor.

20. (Amended) A micromotor according to claim 17 wherein, when the transistor is off, one end of the Mosfet is at a DC voltage equal to the peak of the oscillating voltage and the oscillating voltage is impressed across the Mosfet transistor, such that the voltage across the transistor is substantially unipolar.

21. (Amended) A micromotor according to claim 1 wherein said source comprises an inverter.

33. (Amended) A micromotor according to claim 29 wherein the capacitance of said ultrasonic motor and the inductances of the series inductance and of said transformer match the electrical circuit to the mechanical resonance of said piezoelectric element.

36. (Amended) A micrometer according to claim 29 wherein said push-pull inverter includes a buck section for controlling the amplitude of the voltage connected to said primary of said transformer.

38. (Amended) A micromotor according to claim 29 wherein the second input is ground.

39. (Amended) A micromotor according to claim 29 wherein the first input is electrified with a DC voltage.

40. (Amended) A method of supplying switchable AC power to a micromotor comprising:  
connecting a first terminal of an AC power source to one side of the micromotor;  
connected a drain of a Mosfet transistor to a second terminal of the AC power source ;  
connecting a source of the Mosfet transistor to the other side of the micromotor and  
selectively supplying power to the load by applying a voltage between a gate of the Mosfet  
and the second AC terminal.
43. (Amended) A method according to claim 40 and including placing a capacitor in series  
with the load.
45. (Amended) A method according to claim 40 wherein, when the transistor is off, one end  
of the Mosfet is at a DC voltage equal to the peak voltage of the AC source and AC voltage of the  
AC source is impressed across the Mosfet transistor, such that the voltage across transistor is  
substantially unipolar.
46. (NEW) A micromotor according to claim 7 wherein fewer than four switches are provided  
for selectively controlling at least two directions of said displacement.
47. (NEW) A micrometer according to claim 46 wherein said fewer than four discrete switches are  
a single discrete switch per direction of displacement.

**REMARKS**

The present application is a US national application of PCT/IL98/00519. The present amendments, based on *the claims as originally filed*, have been made to place the application in proper US form and to clarify the claims. *Please ignore the claims attached to the IPER.* The application contains claims 1, 2, 4-11 and 13-47. Claims 46 and 47 have been added and claims 3 and 12 have been canceled.

A marked-up version of the *new and amended* claims, based on the originally filed claims, is attached hereto.

An action on the merits is respectfully awaited.

Respectfully submitted,  
S. BEN-YAAKOV

  
Paul FENSTER  
Reg. No. 33,877

April 22, 2001  
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**Marked-up amended and new claims**

1. (Amended) A micromotor comprising:

a piezoelectric element ~~having~~including a common electrode and a plurality of  
 5 other electrodes, including at least a first and a second electrode group, formed thereon,  
 and ~~including at least a first and a second electrode group~~, each group including at least  
 one electrode, ~~wherein the piezoelectric element causes motion in a first direction when a~~  
~~voltage is applied between the first electrode group and the common electrode and~~  
~~wherein the piezoelectric element causes motion in a second direction when a voltage is~~  
 10 ~~applied between the second electrode group and the common electrode;~~

~~a~~ voltage source that produces a time varying voltage between first and second  
terminals thereof, said first terminal being connected to~~electrifies~~ the common electrode  
and said second electrode being connected to a low voltage; and

a switching arrangement having at least one first switch connected between said first  
 15 group of electrodes and the second terminal of the power supply and a having at least one  
second switch connected between said second group of electrodes and the common  
electrode; and

a controller that selectively energizes the switches to selectively connect either the  
first or the second group of electrodes to the second terminal, said selective connection  
 20 causing selective motion either a first direction or in an opposite second direction.

~~at least two switches separately connected between the first and second electrode groups~~  
~~and a low voltage, said switches being activatable to connect one of said first and second~~  
~~electrode groups to the low voltage to cause selective motion in the first or second~~  
~~directions.~~

4. (Amended) A micromotor according to claim 1~~any of the preceding claims~~ wherein the  
 piezoelectric element comprises a rectangular piezoelectric plate having first and second  
 faces wherein the common electrode is formed on the first face and the first and second  
 groups of electrodes are formed on the second face.

6. (Amended) A micromotor according to claim 1~~any of the preceding claims~~ wherein the  
 micromotor comprises a motive surface and wherein motion is induced in a surface of a



workpiece pressed against the motive surface when the piezoelectric element is electrified as aforesaid.

7. (Amended) A micromotor comprising:

- 5           an ultrasonically vibrating element; and  
           a drive circuit comprising:

                  an oscillating voltage source having a high voltage side connected to and electrifying at least one electrode of said ultrasonically vibrating element to cause a mechanical displacement of a portion thereof; and

- 10           a discrete switch arrangement attached to at least one additional electrode of said ultrasonically vibrating element to which said oscillating voltage is not connected which switch arrangement selects the direction of said displacement.

9. (Amended) A micromotor according to claim 7 ~~or claim 8~~, wherein:

- 15           the at least one additional electrode comprises a plurality of electrodes applied to a first face of said vibrating element; and

                  the at least one electrode comprises a common electrode applied to a second face of said element.

- 20   13. (Amended)       A micromotor according to claim ~~11~~2 wherein said switches of said ~~discrete~~ switching arrangement are solid state switches.

14. (Amended)       A micromotor according to claim ~~12~~ or 13 wherein said switches of said ~~discrete~~ switching arrangement comprise transistorized switches.

- 25   15. (Amended)       A micromotor according to claim 14 wherein said switches of said ~~discrete~~ switching arrangement are Mosfet transistors.

- 30   18. (Amended)       A micromotor according to claim 16 ~~or claim 17~~ and including a pair of diodes, one of which is connected across each said Mosfet transistor.

20. (Amended)       A micromotor according to claim 17 ~~any of claims 17-19~~ wherein, when the transistor is off, one end of the Mosfet is at a DC voltage equal to the peak of the

oscillating voltage and the oscillating voltage is impressed across the Mosfet transistor, such that the voltage across the transistor is substantially unipolar.

21. (Amended) A micromotor according to claim 1~~any of the preceding claims~~  
5 wherein said source comprises an inverter.

33. (Amended) A micromotor according to claim 29~~any of claims 29-31~~ wherein the capacitance of said ultrasonic motor and the inductances of the series inductance and of said transformer match the electrical circuit to the mechanical resonance of said  
10 piezoelectric element.

36. (Amended) A micrometer according to claim 29~~any of claims 29-35~~ wherein said push-pull inverter includes a buck section for controlling the amplitude of the voltage connected to said primary of said transformer.  
15

38. (Amended) A micromotor according to claim 29~~any of claims 29-37~~ wherein the second input is ground.

39. (Amended) A micromotor according to claim 29~~any of claims 29-38~~ wherein  
20 the first input is electrified with a DC voltage.

40. (Amended) A method of supplying switchable AC power to a micromotor~~load~~ comprising:

connecting a first terminal of an AC power source to one side of the  
25 micromotor~~load~~;

connected a drain of a Mosfet transistor ~~to between~~ a second terminal of the AC power source ~~and the other side of the load~~;

connecting a source of the Mosfet transistor to the other side of the micromotor  
and

30 selectively supplying power to the load by applying a voltage between a gate of the Mosfet and the second AC terminal.

43. (Amended) A method according to claim 40~~any of claims 40-42~~ and including placing a capacitor in series with the load.

45. (Amended) A method according to claim 40~~any of claims 40-44~~ wherein, when  
5 the transistor is off, one end of the Mosfet is at a DC voltage equal to the peak voltage of the AC source and AC voltage of the AC source is impressed across the Mosfet transistor, such that the voltage across transistor is substantially unipolar.

46. (NEW) A micromotor according to claim 7 wherein fewer than four switches are  
10 provided for selectively controlling at least two directions of said displacement.

47. (NEW) A micrometer according to claim 46 wherein said fewer than four discrete switches are a single discrete switch per direction of displacement.

DRIVER FOR PIEZOELECTRIC MOTORS**FIELD OF THE INVENTION**

The present invention relates to systems for driving piezoelectric actuators and piezoelectric motors and more particularly to the electronic circuitry of such drivers.

**BACKGROUND OF THE INVENTION**

Piezoelectric materials are characterized in that when they are subjected to electrical fields they can be made to deflect; i.e., produce mechanical motion. Also when mechanical stress is applied to piezoelectric elements so that they undergo displacement they generate electrical signals. These characteristics are the reason that piezoelectric materials are useful in applications ranging from sensors to mechanical motors. Examples of piezoelectric elements being used as motors is shown for example in US patents 5,714,833 and 5,777,423; which patents are assigned to the assignee of the invention of this application. Piezoelectric motors are characterized by their mechanical simplicity. They have very few parts, no separate moving parts, and there are no critical mechanical components such as gears, shafts, bearings etc. Consequently, piezoelectric motors are relatively inexpensive and highly reliable.

A piezoelectric element represents an electrical reactive load (mainly capacitive) that requires an AC signal of substantial voltage amplitude to cause the mechanical displacement. The required voltage amplitude is generally in the range of a few hundred volts (RMS). For effectively operating the piezoelectric element as a motor or actuator a drive circuit applies voltage thereto of a specific frequency with low harmonic distortion. For the best results, i.e. maximum displacement, the specific frequency should equal the mechanical resonant frequency of the piezoelectric element. A simplified circuit that could be used to drive a piezoelectric motor is shown in Fig. 1A, while such a motor is illustrated in Fig. 1B. This method required two sources and two matching (high-Q) resonant circuits (not shown).

A preferred manner of actuating bidirectional operation of the piezoelectric element provides one side of the element with a pair of electrodes that are connected to a voltage source, such as a switch mode inverter. An opposite side of the piezoelectric element has a single common electrode. The common electrode is grounded or connected to ground by passive or active elements so that current from each of the pair of electrodes flows in opposite directions to cause bidirectional displacement of the piezoelectric element.

The drive circuits for piezoelectric motors basically provide AC voltages to the electrodes according to the directional movement required or desired. Typical prior art drive circuits for actuating the piezoelectric elements to provide movement in a selected direction or selected directions comprise separate inverter circuits coupled to the piezoelectric element

through resonant circuitry attached to each of the elements high side electrodes. The prior art utilizes such multiple inverters to cause directional motion of the piezoelectric motors without any separate switching units. Other prior art devices utilize a single high voltage source and switching circuitry to switch the source between different electrodes. This methodology requires high voltage capable switching circuitry.

A major disadvantage of the prior art drivers is the complexity of the circuitry that is used. For example, a commonly used driver comprises a bridge type inverter circuit (see Fig. 2) that requires six power switches, and two high Q resonant circuits. The high Q resonant circuits are sensitive to the accuracy of the circuit component and to the frequency of the applied voltage. As a practical solution for overcoming this sensitivity, in the prior art the Q of the drivers was often lowered and the input voltage from the prior art drivers was raised. Extra DC/DC converters were required to enable operation with lower input voltages. Consequently, in the prior art, while the piezoelectric motors are simple the driver circuitry has until now been complex, especially when driving piezoelectric motors in two directions.

## SUMMARY OF THE INVENTION

Accordingly, it is an object of some preferred embodiments of the present invention to provide drivers for piezoelectric elements that are reliable, simple and of low cost.

It is an object of some preferred embodiments of the present invention is to provide drivers for piezoelectric elements that operate the piezoelectric elements as actuators or motors bi-directionally with a minimum of components.

It is an object of some preferred embodiments of the invention to provide bi-directional drivers for piezoelectric motors or actuators in which a single high voltage unswitched drive circuit is used for both direction of motion.

It is an object of some preferred embodiments of the present invention to provide bi-directional drivers for piezoelectric motors or actuators in which the direction of motion is changed by switching circuitry located at a low voltage connection of the control circuitry.

It is an object of some preferred embodiments of the present invention to provide drivers for piezoelectric elements that utilize soft switching so as to minimize switching losses and increase the overall efficiency of the piezoelectric driver unit and to improve electromagnetic compatibility.

It is an object of some preferred embodiments of the present invention to provide a piezoelectric driver operated from a low DC voltage source without additional complexity.

It is an object of some preferred embodiments of the present invention to provide a discrete bidirectional switching circuit used in conjunction with an AC voltage provided for operating a piezoelectric motor or other AC load.

Some prior art driver circuits for driving piezoelectric motor from a DC voltage source, integrally, combined switching and inverter circuitry. That is the inverters did the switching of the inverter output to the piezoelectric element's electrodes without any discrete switching circuitry. The present invention separates the inverter and switching portions of the driver circuitry by providing discrete switching circuitry. Surprisingly, the result is a circuit for driving the piezoelectric element bidirectionally of decreased complexity using fewer components and operating more reliably.

In accordance with one aspect of the invention, a driver circuit for driving a piezoelectric type motor comprises an inverter circuit for providing an oscillating voltage to cause a mechanical displacement of a piezoelectric element and a separate switching arrangement for selecting the direction of said displacement. The driver circuit in the invention of this application delivers the driving voltages to the piezoelectric element at the mechanical resonant frequency of said piezoelectric element.

In a preferred embodiment of the invention a discrete switch arrangement includes high frequency switches for selectively applying voltages across said piezoelectric element to cause mechanical displacement of the piezoelectric element in a selected direction or selected directions. In preferred embodiments of the invention, the switches are on a low voltage side of the connection to the piezoelectric element.

There is thus provided, in accordance with a preferred embodiment of the invention, a micromotor comprising:

a piezoelectric element including a common electrode and a plurality of other electrodes formed thereon and including at least a first and a second electrode group, each group including at least one electrode, wherein the piezoelectric element causes motion in a first direction when a voltage is applied between the first electrode group and the common electrode and wherein the piezoelectric element causes motion in a second direction when a voltage is applied between the second electrode group and the common electrode;

an voltage source that electrifies the common electrode; and

at least two switches separately connected between the first and second electrode groups and a low voltage, said switches being activatable to connect one of said first and second electrode groups to the low voltage to cause selective motion in the first or second directions.

Preferably, the low voltage is substantially ground. Preferably, the applied voltage is an AC voltage.

In a preferred embodiment of the invention, where the piezoelectric element comprises a rectangular piezoelectric plate having first and second faces, the common electrode is formed on the first face and the first and second groups of electrodes are formed on the second face. Preferably, the first and second groups of electrodes each comprises two electrodes situated in opposite quadrants of the second face.

Preferably, the micromotor comprises a motive surface and motion is induced in a surface of a workpiece pressed against the motive surface when the piezoelectric element is electrified as aforesaid.

There is further provided, in accordance with a preferred embodiment of the invention, a micromotor comprising:

an ultrasonically vibrating element; and

a drive circuit comprising:

an oscillating voltage source connected to and electrifying at least one electrode of said ultrasonically vibrating element to cause a mechanical displacement of a portion thereof; and

a discrete switch arrangement attached to at least one additional electrode of said ultrasonically vibrating element to which said oscillating voltage is not connected which switch arrangement selects the direction of said displacement.

Preferably, the ultrasonically vibrating element comprises a piezoelectric element.

Preferably, the at least one additional electrode comprises a plurality of electrodes applied to a first face of said vibrating element; and the at least one electrode comprises a common electrode applied to a second face of said element. Preferably, the discrete switch arrangement selectively applies voltage between a first group of said plurality of electrodes and said common electrode to cause displacement in a first direction, said first group including at least one electrode. Preferably, the discrete switch arrangement selectively applies voltage between a second group of said plurality of electrodes and said common electrode to cause displacement in a second direction, said second group comprising at least one electrode.

In a preferred embodiment of the invention, the discrete switching arrangement comprises a pair of switches connected to apply voltages across said element to drive current through said element, and controls for selectively operating said switches to select the direction of said displacement. Preferably, the switches of said discrete switching arrangement

comprise solid state switches, preferably, transistorized switches and most preferably, Mosfet transistors.

In a preferred embodiment of the invention, the discrete switch arrangement comprises:

5 a first Mosfet connected between a first voltage and said first group of electrodes;  
a second Mosfet connected between said first voltage and said second group of electrodes, said common electrode being connected to a second voltage, and  
a control that selectively operates said Mosfet switches to selectively apply said first voltage to the first electrode group or to said second electrode group.

10 Preferably, the micromotor includes a source of control voltages selectively applied to the gates of said first and second Mosfet transistors for selectively switching said first or said second Mosfet transistors from the non conducting state to the conducting state.

Preferably, the micromotor includes a pair of diodes, one of which is connected across each said Mosfet transistor. Preferably, the diodes are connected such that they conduct DC  
15 current toward the micromotor.

In a preferred embodiment of the invention, the transistor is off, one end of the Mosfet is at a DC voltage equal to the peak of the oscillating voltage and the oscillating voltage is impressed across the Mosfet transistor, such that the voltage across transistor is substantially unipolar.

20 In a preferred embodiment of the invention, the source comprises an inverter, preferably, a forward-flyback inverter.

Preferably, the forward-flyback inverter comprises:

a magnetic element having a primary winding and a secondary winding, said primary winding being connected between a first inverter voltage and one side of an inverter operating  
25 switch, the other side of said inverter operating switch connected to a second inverter voltage so that when said inverter operating switch is in the conductive stage, current flows through said primary and when said inverter operates switch is in a non conductive state substantially no current flows through said primary; and

a control voltage source which selectively turns said inverter operating switches switch  
30 on or off, the secondary of said magnetic element being connected to said discrete switching arrangement.

Preferably, the inverter operating switches comprise solid state switches, preferably transistorized switches, most preferably, Mosfet transistor, and further comprises circuitry that



causes said inverter output to resonate at substantially the mechanical resonant frequency of said piezoelectric element.

In a preferred embodiment of the invention, the circuitry that causes said inverter output to resonate at substantially the mechanical resonant frequency of the piezoelectric  
5 comprises a capacitor bridging said switch and in series with the primary of the magnetic element, said capacitor operating in conjunction with the capacitance of said ultrasonically vibrating motor to turn said magnetic element to resonate at substantially the mechanical resonant frequency of the motor.

In a preferred embodiment of the invention, the inverter is a push-pull inverter.

10 Preferably, the push-pull inverter comprises a transformer, having a primary and a secondary;

a series inductor connecting a first inverter input to a mid part of the primary of said transformer,

the secondary of said transformer connected to said discrete switching arrangement  
15 and one side of the primary of said transformer being connected through a first push-pull inverter switch to a second inverter input,

the other side of said primary of said transformer being connected through a second push-pull inverter switch to said second input.

20 Preferably, the first and second push-pull switches comprise solid states switches, more preferably, transistorized switches and most preferably, Mosfet type switches.

In a preferred embodiment of the invention, the capacitance of said ultrasonic motor and the inductances of the series inductance and of said transformer match the electrical circuit to the mechanical resonance of said piezoelectric element. Preferably, the first or the second push-pull inverter switches are each selectively operated by control voltages, preferably,  
25 square wave voltages.

In a preferred embodiment of the invention, the push-pull inverter includes a buck section for controlling the amplitude of the voltage connected to said primary of said transformer. Preferably, the buck section includes:

30 a series buck section switch connected between the first input of the inverter and the series inductor;

a diode connected between an output of the buck section switch and said second input of the inverter and,

a control voltage operative to cause the buck section switch to conduct.

In a preferred embodiment of the invention, the second input is ground. Preferably, the first input is electrified with a DC voltage.

There is further provided, in accordance with a preferred embodiment of the invention, a method of supplying switchable AC power to a load comprising:

- 5       connecting a first terminal of an AC power source to one side of the load;
- connected a Mosfet transistor between a second terminal of the AC power source and the other side of the load; and
- selectively supplying power to the load by applying a voltage between a gate of the Mosfet and the second AC terminal.

- 10       Preferably a diode is connected across the Mosfet. Preferably, the diode is connected such that it conducts current between the second terminal and the other side of the load.

In a preferred embodiment of the invention a capacitor is placed in series with the load, which preferably, does not include a DC blocking capacitor.

- 15       In accordance with a preferred embodiment of the invention, when the transistor is off, one end of the Mosfet is at a DC voltage equal to the peak voltage of the AC source and AC voltage of the AC source is impressed across the Mosfet transistor, such that the voltage across transistor is substantially unipolar.

### BRIEF DESCRIPTION OF THE DRAWINGS

- 20       The above named and other features and objects of the present invention will be best understood from the following description of preferred embodiments of the invention taken in conjunction with the accompanying drawings, in which:

Figs. 1A and 1B are a simplified schematic showing of a bi-directional piezoelectric motor and associated driver circuitry of the prior art;

- 25       Fig. 2 is prior art bridge circuit implementation of a bi-directional piezoelectric motor driver;

Fig. 3 is a basic electrical component schematic showing of an AC switch operating a piezoelectric motor;

Fig. 4 is a schematic showing of a discrete bi-directional switch used with a piezoelectric motor;

- 30       Fig. 5 is a schematic showing of a preferred driver circuit comprising a forward-flyback inverter used in conjunction with the bi-directional switch for operating the piezoelectric motor;

Fig. 6 is an equivalent circuit of Fig 5 showing elements of the secondary circuitry reflected to the primary;

Fig. 7 is the schematic showing of the circuit of Fig 6 when the switch  $Q_{ff}$  is conducting;

Fig 8 is a schematic showing of the circuit of Fig 6 when the switch  $Q_{ff}$  is non-conducting;

5 Fig 9 is a schematic showing of a preferred driver circuit comprising a push-pull parallel resonant inverter used in conjunction with the bi-directional switch for operating the piezoelectric motor;

Fig. 10 is a schematic showing of the push-pull inverter of Fig 9 including a buck section providing output voltage control; and

10 Fig 11 is a showing of the voltage wave form at point A of Fig. 10.

### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Figs. 1A and 1B are a simplified schematic showing of a bi-directional piezoelectric motor as used in the prior art to aid in understanding the invention. The piezoelectric motor 11, comprises a piezoelectric crystal or ceramic element 12, that operates responsive to  
15 electric voltage thereacross to provide mechanical displacement.

As shown in Figs. 1A and 1B, to operate the motor bi-directionally, two pairs of electrodes 13 and 14 are attached to a first face 16 of element 12 and a common electrode 17 is attached to and covers substantially all of an opposite face 18 of element 12. Common electrode 17 is grounded at 19. A first AC voltage  $V_1$  is applied between electrodes 14 and 17  
20 by the operation of switch  $SW_1$  responsive to a control signal  $S_1$ . Voltage  $V_1$  causes mechanical displacement of a surface pressed against an extension 9 of element 12 in a first direction.

Operation of switch  $SW_2$ , responsive to a control signal  $S_2$ , applies a second AC voltage  $V_2$  between electrodes 13 and 17. Voltage  $V_2$  causes mechanical displacement of a  
25 surface pressed against extension 9 in a second direction. The piezoelectric element 12 is reactive in nature and mechanically resonates at particular frequencies in transverse directions.

It should be understood that when electrodes are shown, in the following drawings, in the manner of electrodes 13 and 14, what is meant is a configuration such as that shown in Fig. 1B.

30 Fig. 2 shows a typical prior art implementation of a bi-directional driver for a piezoelectric motor. A prior art bi-directional inverter driver as shown in Fig. 2 has a positive supply voltage  $V_{in}$  applied to conductor 21. A switch shown as  $Q_1$  is connected to conductor 21. The switch is shown as a Mosfet type transistor with the source 22 connected to the conductor 21. The switch  $Q_1$  in the preferred embodiment is operated to the conducting state

by a pulsed gate control signal S1 applied to gate DR1. Responsive to the gate control signals the switch Q1 applies DC voltage  $V_{in}$  as pulses to the drain 23 of switch Q1. The drain 23 is connected to conductor 24 which connects to common electrode 17 of piezoelectric motor 11. Conductor 24 is connected to ground through switch Q2 operated to the conducting condition  
5 in response the pulsed control signal S2 applied on the gate DR2 of switch Q2. The source 26 of switch Q2 is connected to conductor 24 and the drain 27 of switch Q2 is connected to ground 28 through conductor 29.

Electrodes 14 of piezoelectric motor 11 is connected to the junction of a capacitor C1 and an inductor L1. Capacitor C1 and inductor L1 form a resonant circuit tuned to the  
10 mechanical resonance frequency of the piezoelectric motor. The other side of capacitor C1 is connected to conductor 24. The other side of inductor L1 is connected through conductor 30 to the junction of another pair of switches, Q5 and Q6. Transistor switches Q5 and Q6 operate to the conductive state responsive to pulsed signals S5 and S6 on the gate drivers shown as DR5 and DR6. The source 31 of switch Q5 is coupled to the DC voltage  $V_{in}$  on conductor 21. The  
15 drain 32 of switch Q5 is coupled to the source 33 of switch Q6. The drain 34 of switch Q6 is coupled is to ground conductor 29.

Another half bridge circuit connects electrodes 13 of the motor 11 to source voltage  $V_{in}$ . More particularly, the electrode 13 of the motor 11 is connected to the junction of inductor L2 and capacitor C2 which form a second resonant circuit. The other side of capacitor  
20 C2 is connected to conductor 24. The other side of inductor L2 is connected to the junction of the drain 36 of switch Q3 and the source 37 of switch Q4. The source 38 of switch Q3 is coupled to the DC voltage  $V_{in}$  on conductor 21. The drain 39 of switch Q4 is coupled to the grounded conductor 29. The switches Q2, Q4 are operated responsive to signals S3, S4.

In operation, Q1 and Q2 act together with either Q3 and Q4 or Q5 and Q6 to apply an  
25 oscillating voltage to the resonant circuit of L1/C1 or L2/C2 respectively, in a manner well known in the art. Depending on which half bridge is operated together with Q1/Q2, either electrodes 13 or 14 will be energized. This allows for reversible motion of a surface pressed against extension 9.

In greater detail when switches Q1, Q2 and Q5, Q6 are operated, an AC voltage is  
30 applied between electrodes 14 and 17 of the motor 11 at the resonant frequency set by capacitor C1 and inductor L1. Alternatively, an AC voltage is applied between electrodes 13 and 17 by the operation of switches Q1, Q2 and Q3, Q4. This applies an AC voltage across electrodes 13 and 17 at the resonant frequency set by inductor L2 and capacitor C2. Thus, the voltage across electrodes 13 and 17 responsive to the operation of switches Q1- Q4 cause the

motor to operate in one direction and the operation of switches Q1, Q2 and Q5, Q6 cause the motor to operate in the opposite direction. This typical prior art circuitry requires two high Q resonant circuits, C1, L1 and C2, L2 and six switching components operated responsive to signals S1-S6 applied to the gates DR1-DR6.

5 A high voltage  $V_{in}$  is needed across the motor if reasonable Q factors are to be used. For example, a Q factor of 5 requires the input voltage to be about 1/5 of the required motor voltage. A motor voltage of 400 volts is reasonable. This implies that the input voltage needs to be 80 volts. If lower voltages are required then additional circuitry would have to be added.

Fig. 3 shows an AC switch and equivalent circuit of the piezoelectric device,  
10 respectively, useful in understanding preferred embodiments of the invention.

In Fig. 3,  $L_s/C_s$  represent the mechanical resonance of the piezoelectric device,  $R_s$  represents mechanical work and losses and  $C_p$  is the electrode capacitance. Since  $C_p$  is very large, an inductor is usually added in series with the piezoelectric device.

When switch SWL is closed,  $V_s$  is applied to the piezoelectric device and the motor  
15 operates. When SWL is open, capacitor  $C_p$  is clamped to the peak value of  $V_s$  via diode  $D_s$ . This DC voltage is maintained so long as SWL is open. In this situation, (DC voltage across the piezoelectric element) the motor does not operate. AC Voltage appears across the diode.

Fig. 4 shows a preferred embodiment of the discrete bidirectional AC switch for operating with an AC voltage  $V_s$  to drive piezoelectric motor 11. As in Fig. 1, piezoelectric  
20 motor 11 comprises electrodes 13, 14 on one face and electrode 17 on the opposite face of piezoelectric element 12. While any solid state switching units can be used, in a preferred embodiment there two Mosfet switches  $M_{S1}$  and  $M_{S2}$ , each connected to electrodes 13 and 14 respectively are used as the switches. Diodes  $D_{S1}$  and  $D_{S2}$  shown as connected across the switches  $M_{S1}$  and  $M_{S2}$  are inherent in Mosfet transistors. Source 41 of switch  $M_{S1}$  and diode  
25  $D_{S1}$  are both connected to electrodes 13 of motor 11. Drain 42 of switch  $M_{S1}$  and the other side of diode  $D_{S1}$  are shown as being grounded at 43. Source 44 of switch  $M_{S2}$  is connected to the anode of diode  $D_{S2}$  and to electrodes 14. Drain 46 of switch  $M_{S2}$  is connected ground 43 through conductor 47. One side of the alternating voltage source is connected to the common electrode 17 of the piezoelectric motor 11 while the other side of the voltage source  
30 is coupled to ground through conductor 47. The operating direction of the piezoelectric motor 11 is controlled by gate voltages  $V_{gs1}$  and  $V_{gs2}$  applied to the gates of switches  $M_{S1}$  and  $M_{S2}$  respectively. When  $M_{S1}$  is closed (and  $M_{S2}$  is open), the AC voltage is applied between electrodes 17 and 13 and a surface pressed against extension 9 moves in a first direction. When  $M_{S2}$  is closed an  $M_{S1}$  is open, travel is in the reverse direction.

This is facilitated by the fact that when  $MS_2$  is open, it disconnects the AC current path (the AC voltage appears across the switch) from electrode 14. The DC voltage that develops, under these conditions, between electrodes 14 and 17 does not interfere with the operation of the motor, as effected by the AC voltage between electrodes 17 and 13.

5 Major advantages of this bidirectional switching configuration is that:

- a) the control voltages are all referred to ground, and
- b) only one AC source is required.

One reason these advantages are available is that unlike the prior art drivers, the common electrode is not referenced to ground. Rather, one of the electrode pairs 13 or 14 is grounded. This allows for a single power source to feed the common electrode and, since the individual electrodes are near ground, for the switching to be controlled with low voltages.

This switching scheme can be incorporated in conjunction with any inverter driver but it has special merits when the inverter configuration of this invention is used to provide the driving voltage  $V_S$ .

15 A preferred embodiment of the AC source is a forward-flyback type inverter such as schematically shown in Fig. 5. Therein a high frequency switch such as Mosfet transistor  $Q_{ff}$  51 is driven by square wave signal  $V_{SG}$  applied to the gate electrode 52. Source 54 of switch  $Q_{ff}$  is connected to a primary winding 58 of a two winding magnetic element indicated at 53. Drain 56 of switch  $Q_{ff}$  is coupled to ground 57. While many types of switches can be used at  $Q_{ff}$ , the preferred embodiment encompasses a Mosfet type transistor. The diode inherent in the Mosfet transistor is shown as  $D_{ff}$  coupled from drain 56 to source 54 of transistor  $Q_{ff}$ . The other side of the primary winding 58 of the magnetic element 53 is connected to positive DC voltage  $V_{in}$  as shown at 59. The switch  $Q_{ff}$  is bridged by a capacitance  $C_T$  connected between its source 54 and drain, 56. Capacitance  $C_T$  forms a resonant circuit with the other reactive components.

The inverter is preferably connected to piezoelectric element 12 and the pair of discrete bidirectional switches through the secondary winding 61 of the two winding magnetic element 53. The turns ratio between the primary winding 58 and the secondary winding 61 is shown as being 1:n where n in one preferred embodiment is in a range between 2 and 25.

30 One side of winding 61 is preferably connected to ground at 62. The other side is connected to the common electrode 17 of the motor 11. The other electrodes of the motor 11, i.e. electrode pairs 13 and 14 are connected to high frequency switches such as switches  $MS_1$  and  $MS_2$ , in the manner described above with respect to Fig. 4.

The operation of the combination of the discrete inverter and the discrete bi-directional switch, in combination, is more clearly understood with reference to the schematic of Fig. 6. That schematic shows one of the switches open and the other closed with all secondary components (including the closed lines) being reflected to the primary. The inductance of the two element magnetic unit 53 is shown as  $L_{lk}$ , i.e. the leakage inductance of the magnetic element 53. The piezoelectric element 12 of the motor 11 is represented by the impedance  $Z_M$  which is mainly capacitive in the nature at the mechanical resonance frequency. It is shown as being divided by  $n^2$  when reflected into the primary of magnetic unit 53.

A square wave voltage  $V_{sq}$  is shown applied to the gate of switch  $Q_{ff}$  whose drain is connected ground and whose source is connected to inductor  $L_m$  and to motor (impedance) element  $Z_M$ . Diode  $D_{ff}$  is shown as is resonance capacitance  $C_r$ , both bridging switch  $Q_{ff}$ . Capacitance  $C_r$  is in series with and resonates with the inductance  $L_m$  bridged by the leakage inductance  $L_{lk}$  in series with the reactance  $Z_M/n^2$ .

While a square wave operating voltage  $V_{sg}$  is shown; it should be understood that the operating voltage can assume other forms as known in the art within the scope of the invention.

When the switch  $Q_{ff}$  is conducting, as shown in Fig. 7, energy is delivered to the motor in a resonant manner in the two half cycles. When the high frequency switch  $Q_{ff}$  is conducting, energy is transferred from the voltage source to the motor and energy is also stored in inductance  $L_m$ . A resonance circuit is formed between the leakage inductor  $L_{kj}$  and the motor impedance  $Z_m$ . Hence the voltage wave form fed to the motor is sinusoidal.

During a non conducting period of the switch  $Q_{ff}$ , as shown in Fig. 8, the energy stored in the inductance  $L_m$  is transferred to the motor. Notice that the voltage to the motor now is of opposite polarity than the voltage that was applied during the conducting stage of switch  $Q_{ff}$ . Reactive element  $L_m$ , bridged by the series connection of  $L_{kj}$  and  $Z_m/n^2$  forms a resonant circuit that can shape the voltage across the motor to be sinusoidal by properly choosing the circuit parameters. Preferably, this circuit is resonant at the mechanical resonance frequency.

Note that, when the wave form across the switch is sinusoidal, the switch operates under "soft" switching conditions. In other words if switch  $Q_{ff}$  turns off after voltage across it reduces to zero, the switch is turned on under zero voltage conditions. Then, when the switch  $Q_{ff}$  is turned off, the voltage will rise across it relatively slowly due to the action of capacitor  $C_r$ . Hence zero voltage switching at turn off is achieved.

Thus the circuit of Fig. 5, according to this preferred embodiment of the invention, may have one or more of a number of advantages, for example:

i) a single switch is used for implementing the inverter section,  
 ii) all signal drives are referred to one ground,  
 iii) by choosing the proper turns ratio the motor voltage can be made high even if  $V_{in}$  is a low DC voltage,

- 5 iv) the motor signals are of low harmonic content, and in addition  
 v) the total part count is very low, i.e. the inverter section is based on a single transistor and the discrete bidirectional switch has only two transistors.

Further the embodiment of Fig 5 is suitable for relatively low power levels.

10 As can be well understood, the exact design details for such circuitry is a function of the exact physical and electrical parameters. However, the design can be optimized for the particular characteristics of piezoelectric element utilizing design programs such as SPICE or the like. Once such a design is achieved, the components (including the non-ideal transformers used in the designs) may be designed and produced using methods well known in the art or magnetic component design.

15 Another preferred embodiment of the invention is shown in Fig. 9, in which the discrete inverter is of a push-pull configuration. The push-pull configuration is suitable for higher power levels than is the forward flyback inverter. In the push-pull arrangement of the inverter shown in Fig 9, two switches  $Q_{p1}$  and  $Q_{p2}$  operate on the load in a push-pull manner through a resonant network. The resonant network comprises the inductance of a transformer  
 20 TR whose secondary is bridged by capacitor  $C_{pp}$ . Current from the DC voltage  $V_{in}$  is applied to primary 66 of transformer TR through series inductor  $L_{sp}$ . The input to the transformer is to the middle of the primary windings 66 as shown in Fig 9. In a preferred embodiment of the invention, the two switches  $Q_{p1}$  and  $Q_{p2}$  are Mosfet transistors.

One side of primary 66, goes to the source 67 of transistor  $Q_{p1}$ . Drain 68 of transistor  
 25  $Q_{p1}$  is coupled to ground at 69. The other side of the primary winding 66 of transformer TR is coupled to source 72 of switch Q. Drain 73 of transistor switch  $Q_{p2}$  is coupled to ground. Both transistors  $Q_{p1}$  and  $Q_{p2}$  are shown as having square wave control voltages applied to their gates 74 and 76 respectively, for converting the DC voltage input to an AC voltage at the resonant frequency. Control voltages with other waveforms could be used within the scope of  
 30 the invention. The secondary winding n1 of transformer TR, has one side 77 connected to ground and the other side 78 connected to common electrode 17 of motor 11. When the parameters of the circuit are properly chosen the signal fed to the motor 11 will be of a sinusoidal shape with low harmonic distortion.



The major benefit of the push-pull embodiment over the forward-flyback embodiment is the capability to handle higher power levels. Furthermore, by slight modification, the output of voltage of the push-pull embodiment can be further controlled as is illustrated in Fig 11. Here an additional high frequency switch  $Q_{buck}$  and diode  $D_{buck}$  have been added. These elements together with inductor  $L_{sp}$  form a "down" or "buck" inverter. This type of inverter is controlled by the duty cycle  $D_{on}$  of  $Q_{buck}$ . Assuming a sinusoidal wave form, the voltage at point "A" in Fig. 11 will be as shown in Fig 12. The peak value  $V_{pk}$  of this wave form will be related to the motor voltage by the equation:

$$V_{PK} = V_{motor}/n.$$

At steady state, the average voltage across the inductor  $L_{sp}$  will be zero and hence the average of  $V_{pk}$  must be equal to the voltage at point "B" in Fig. 10 which is equal to  $V_{in} \cdot D_{on}$ . Hence:

$$V_{PK} = nV_{in} \cdot D_{on}.$$

Consequently from these equations:

$$V_{motor} = n \cdot V_{in} \cdot D_{on}.$$

Hence the motor voltage can be controlled by varying  $D_{on}$  of  $Q_{buck}$ . This feature is particularly applicable when variable motor voltages, are called for such as for varying the speed of the motor.

The preferred embodiments have been described in relation to a piezoelectric motor having a common electrode on one face of a piezoelectric ceramic and two pairs of electrodes on the other face. However, the motor may also operate more of fewer electrodes and with different configuration. Further it can be adapted to other configurations of piezoelectric motors.

Furthermore, a bipolar switch in accordance a preferred embodiment of the invention may be used for various other applications. In fact many AC loads may be switched using such a bipolar switch. In general, it is difficult to switch an AC load with a single MOS transistor. In accordance with a preferred embodiment of the invention, a switch, such as one half of the circuit shown in Fig. 4, may be used to switch a capacitive AC load, using a single transistor. Furthermore, if the load is not capacitive a large (compared to the admittance of the load) capacitor may be placed in series with the load. For AC purposes (i.e., when the switch is closed) the capacitor has negligible effect. However, when the switch is open, the voltage across the capacitor will rise to the peak of the AC voltage switching the load off, as described above.

Various modifications will be apparent to and will be readily available to those skilled in the art without departing from the scope and spirit of the invention. Accordingly it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein but rather that the claims be broadly construed. It should be understood that the verbs  
5 "comprise" and "include" and their conjugations, when used in the claims, mean "including, but not necessarily limited to."

## CLAIMS

1. A micromotor comprising:

a piezoelectric element including a common electrode and a plurality of other electrodes formed thereon and including at least a first and a second electrode group, each group including at least one electrode, wherein the piezoelectric element causes motion in a first direction when a voltage is applied between the first electrode group and the common electrode and wherein the piezoelectric element causes motion in a second direction when a voltage is applied between the second electrode group and the common electrode;

an voltage source that electrifies the common electrode; and

at least two switches separately connected between the first and second electrode groups and a low voltage, said switches being activatable to connect one of said first and second electrode groups to the low voltage to cause selective motion in the first or second directions.

2. A micromotor according to claim 1 wherein the low voltage is substantially ground.

3. A micromotor according to claim 1 or claim 2 wherein the applied voltage is an AC voltage.

4. A micromotor according to any of the preceding claims wherein the piezoelectric element comprises a rectangular piezoelectric plate having first and second faces wherein the common electrode is formed on the first face and the first and second groups of electrodes are formed on the second face.

5. A micromotor according to claim 4 wherein the first and second groups of electrodes each comprises two electrodes situated in opposite quadrants of the second face.

6. A micromotor according to any of the preceding claims wherein the micromotor comprises a motive surface and wherein motion is induced in a surface of a workpiece pressed against the motive surface when the piezoelectric element is electrified as aforesaid.

7. A micromotor comprising:

an ultrasonically vibrating element; and

a drive circuit comprising:

an oscillating voltage source connected to and electrifying at least one electrode of said ultrasonically vibrating element to cause a mechanical displacement of a portion thereof; and

5 a discrete switch arrangement attached to at least one additional electrode of said ultrasonically vibrating element to which said oscillating voltage is not connected which switch arrangement selects the direction of said displacement.

8. A micromotor according to claim 7 wherein the ultrasonically vibrating element  
10 comprises a piezoelectric element.

9. A micromotor according to claim 7 or claim 8, wherein:

the at least one additional electrode comprises a plurality of electrodes applied to a first face of said vibrating element; and

15 the at least one electrode comprises a common electrode applied to a second face of said element.

10. A micromotor according to claim 9 wherein the discrete switch arrangement selectively applies voltage between a first group of said plurality of electrodes and said  
20 common electrode to cause displacement in a first direction, said first group including at least one electrode.

11. A micromotor according to claim 10, wherein the discrete switch arrangement selectively applies voltage between a second group of said plurality of electrodes and said  
25 common electrode to cause displacement in a second direction, said second group comprising at least one electrode.

12. A micromotor according to any of the preceding claims wherein said discrete switching arrangement comprises a pair of switches connected to apply voltages across said  
30 element to drive current through said element, and controls for selectively operating said switches to select the direction of said displacement.

13. A micromotor according to claim 12 wherein said switches of said discrete switching arrangement are solid state switches.

14. A micromotor according to claim 12 or 13 wherein said switches of said discrete switching arrangement comprise transistorized switches.

5 15. A micromotor according to claim 14 wherein said switches of said discrete switching arrangement are Mosfet transistors.

16. A micromotor according to claim 11 wherein said discrete switch arrangement comprises:

- 10 a first Mosfet connected between a first voltage and said first group of electrodes;  
a second Mosfet connected between said first voltage and said second group of electrodes, said common electrode being connected to a second voltage, and  
a control that selectively operates said Mosfet switches to selectively apply said first voltage to the first electrode group or to said second electrode group.

15

17. A micromotor according to claim 16 including a source of control voltages selectively applied to the gates of said first and second Mosfet transistors for selectively switching said first or said second Mosfet transistors from the non conducting state to the conducting state.

20 18. A micromotor according to claim 16 or claim 17 and including a pair of diodes, one of which is connected across each said Mosfet transistor.

19. A micromotor according to claim 18 wherein the diodes are connected such that they conduct DC current toward the micromotor.

25

20. A micromotor according to any of claims 17-19 wherein, when the transistor is off, one end of the Mosfet is at a DC voltage equal to the peak of the oscillating voltage and the oscillating voltage is impressed across the Mosfet transistor, such that the voltage across the transistor is substantially unipolar.

30

21. A micromotor according to any of the preceding claims wherein said source comprises an inverter.

22. A micromotor according to claim 21 wherein the inverter is a forward-flyback inverter.

23. A micromotor according to claim 22 wherein said forward-flyback inverter comprises:  
a magnetic element having a primary winding and a secondary winding, said primary winding being connected between a first inverter voltage and one side of an inverter operating switch, the other side of said inverter operating switch connected to a second inverter voltage so that when said inverter operating switch is in the conductive stage, current flows through said primary and when said inverter operates switch is in a non conductive state substantially no current flows through said primary; and

a control voltage source which selectively turns said inverter operating switches on or off, the secondary of said magnetic element being connected to said discrete switching arrangement.

24. A micromotor according to claim 23 wherein said inverter operating switches are solid state switches.

25. A micromotor according to claim 23 wherein said inverter operating switches are transistorized switches.

26. A micromotor according to claim 23 wherein said inverter operating switches are Mosfet transistors, and comprising:

circuitry that causes said inverter output to resonate at substantially the mechanical resonant frequency of said piezoelectric element.

27. A micromotor according to claim 26 wherein said circuitry that causes said inverter output to resonate at substantially the mechanical resonant frequency of the piezoelectric comprises a capacitor bridging said switch and in series with the primary of the magnetic element, said capacitor operating in conjunction with the capacitance of said ultrasonically vibrating motor to turn said magnetic element to resonate at substantially the mechanical resonant frequency of the motor.

28. A micromotor according to claim 21 wherein said inverter is a push-pull inverter.

29. A micromotor according to claim 28 wherein said push-pull inverter comprises a transformer, having a primary and a secondary;

a series inductor connecting a first inverter input to a mid part of the primary of said transformer,

the secondary of said transformer connected to said discrete switching arrangement and one side of the primary of said transformer being connected through a first push-pull inverter switch to a second inverter input,

the other side of said primary of said transformer being connected through a second push-pull inverter switch to said second input.

30. A micromotor according to claim 29 wherein said first and second push-pull switches are solid states switches.

31. A micrometer according to claim 30 wherein said first and second push-pull inverter switches are transistorized switches.

32. A micromotor according to claim 30 wherein said first and second push-pull inverter switches are Mosfet type switches.

33. A micromotor according to any of claims 29-31 wherein the capacitance of said ultrasonic motor and the inductances of the series inductance and of said transformer match the electrical circuit to the mechanical resonance of said piezoelectric element.

34. A micromotor according to claim 33 wherein the first and the second push-pull inverter switches are each selectively operated by control voltages.

35. A micromotor according to claim 34 wherein the control voltages are square wave voltages.

36. A micrometer according to any of claims 29-35 wherein said push-pull inverter includes a buck section for controlling the amplitude of the voltage connected to said primary of said transformer.

37. A micromotor according to claim 36 wherein said buck section includes:

a series buck section switch connected between the first input of the inverter and the series inductor;

a diode connected between an output of the buck section switch and said second input of the inverter and,

a control voltage operative to cause the buck section switch to conduct.

5 38. A micromotor according to any of claims 29-37 wherein the second input is ground.

39. A micromotor according to any of claims 29-38 wherein the first input is electrified with a DC voltage.

10 40. A method of supplying switchable AC power to a load comprising:  
connecting a first terminal of an AC power source to one side of the load;  
connected a Mosfet transistor between a second terminal of the AC power source and  
the other side of the load; and  
selectively supplying power to the load by applying a voltage between a gate of the  
15 Mosfet and the second AC terminal.

41. A method according to claim 40 and including connecting a diode across the Mosfet transistor.

20 42. A method according to claim 41 wherein the diode is connected such that it conducts current between the second terminal and the other side of the load.

43. A method according to any of claims 40-42 and including placing a capacitor in series with the load.

25

44. A method according to claim 43 wherein the load does not comprise a DC blocking capacitor.

30 45. A method according to any of claims 40-44 wherein, when the transistor is off, one end of the Mosfet is at a DC voltage equal to the peak voltage of the AC source and AC voltage of the AC source is impressed across the Mosfet transistor, such that the voltage across transistor is substantially unipolar.



1/7

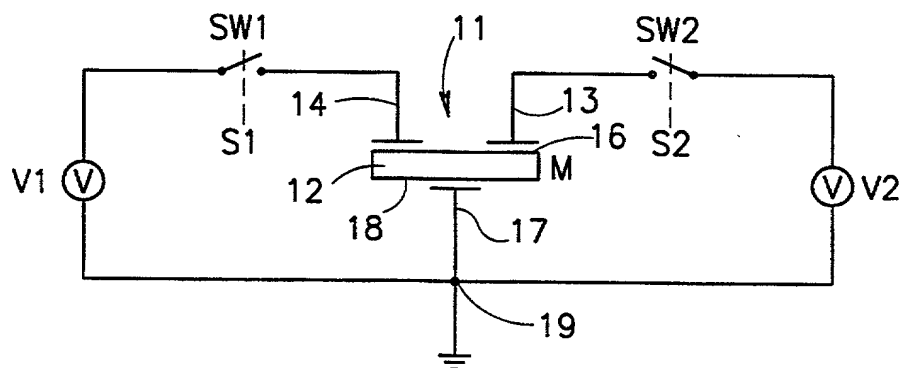


FIG. 1A  
PRIOR ART

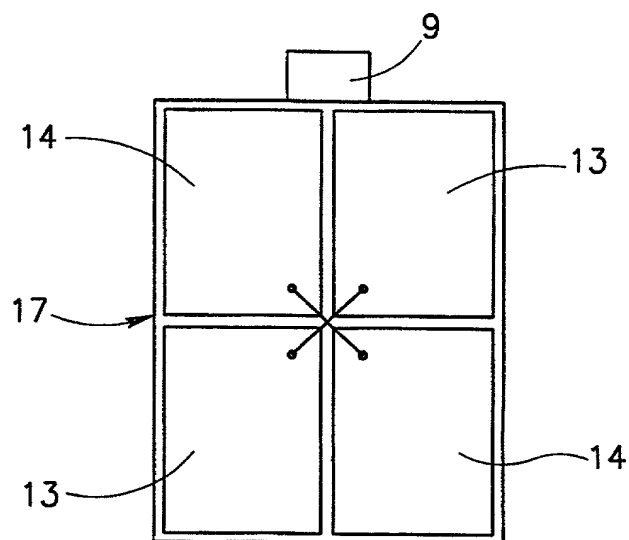


FIG. 1B

FIG.2  
PRIOR ART

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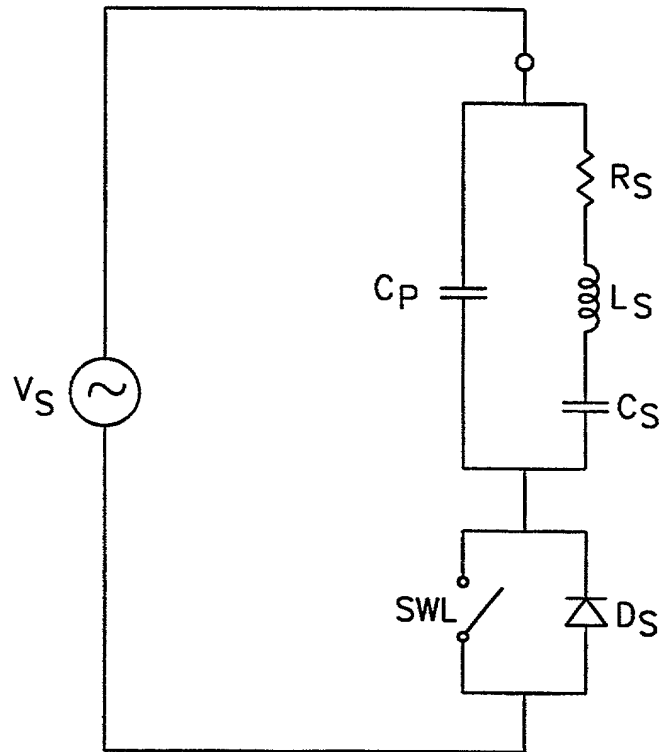


FIG.3

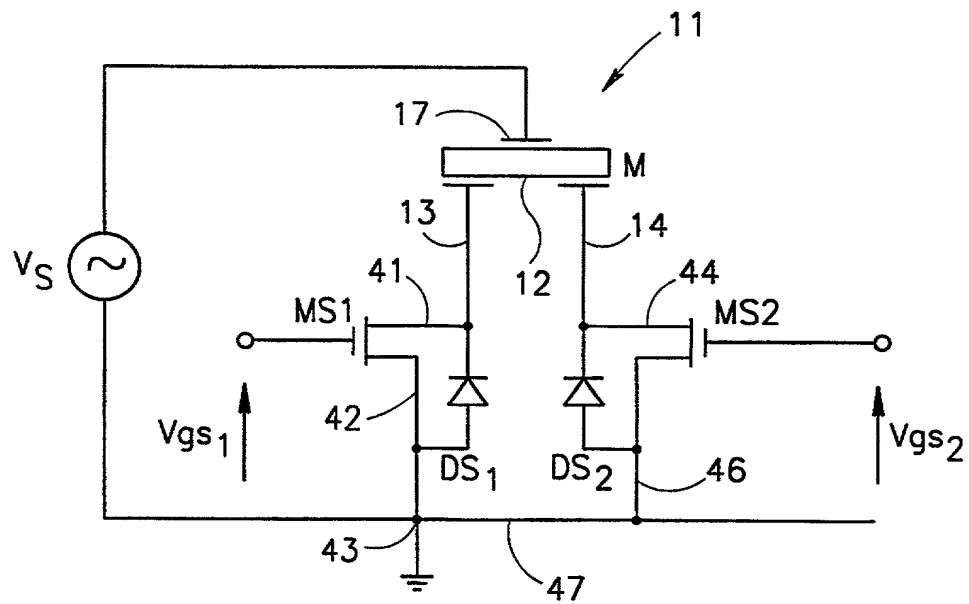


FIG.4



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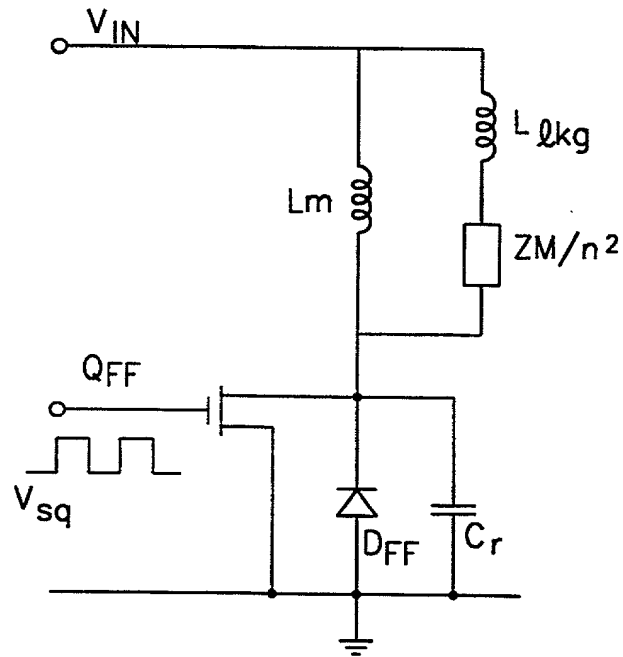


FIG. 6

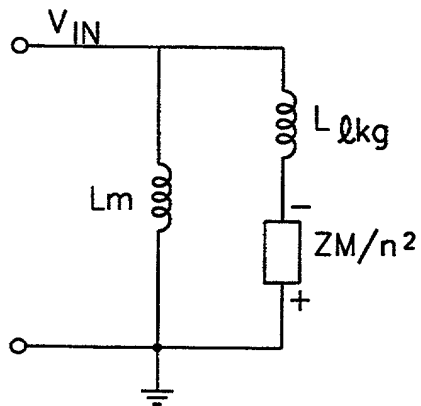


FIG. 7

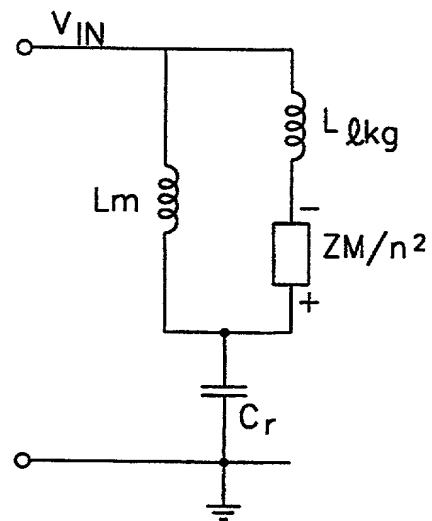


FIG. 8

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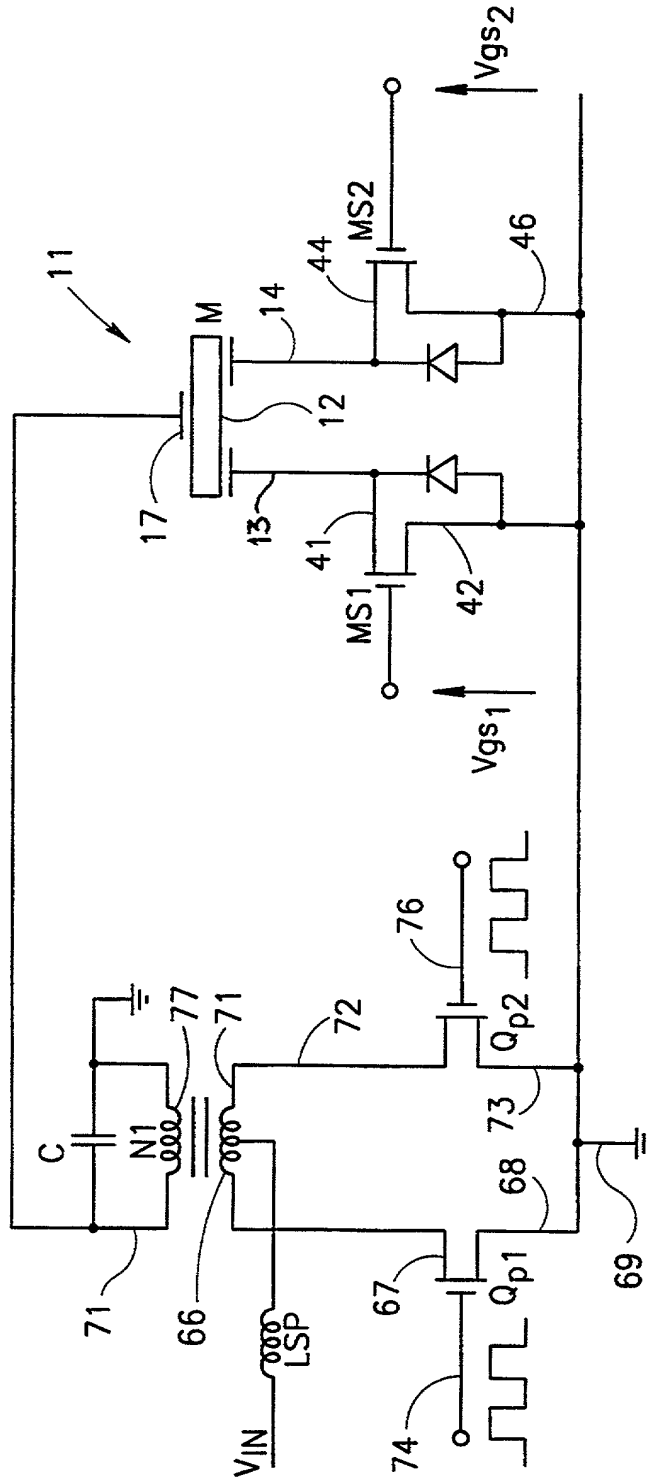


FIG. 9

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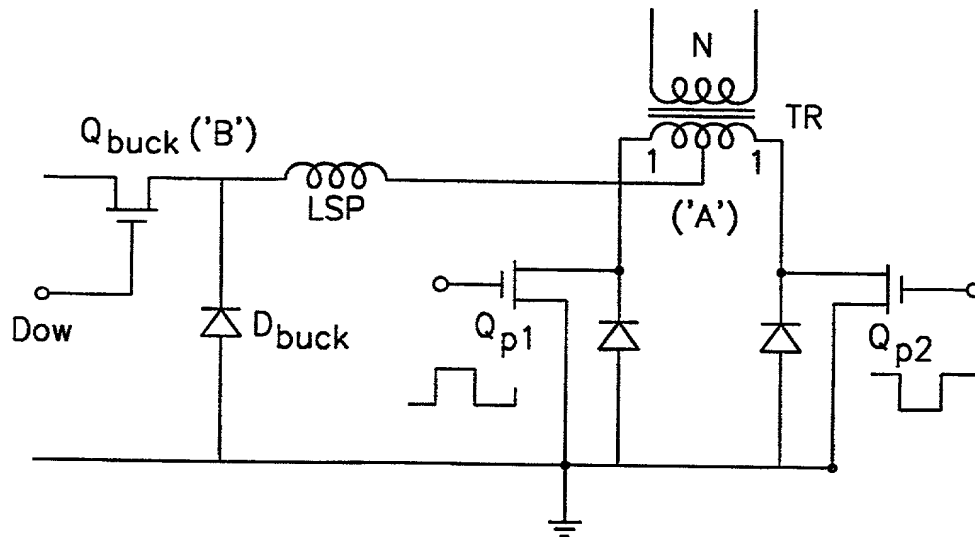


FIG.10

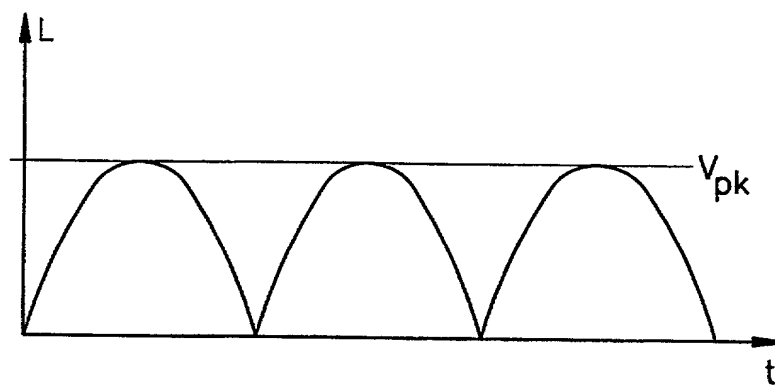


FIG.11

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# Declaration and Power of Attorney For Patent Application

## English Language Declaration

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

**DRIVER FOR PIEZOELECTRIC MOTORS**

the specification of which

(check one)

☐ is attached hereto.

☒ was filed on October 25, 1998 as United States Application No. or PCT International

Application Number PCT/IL98/00519

and was amended ☒ as in the annexes to the International Preliminary Examination Report

(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) or Section 365(b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)

Priority Not Claimed

(Number)

(Country)

(Day/Month/Year Filed)

☐

(Number)

(Country)

(Day/Month/Year Filed)

☐

(Number)

(Country)

(Day/Month/Year Filed)

☐



I hereby claim the benefit under 35 U.S.C. Section 119(e) of any United States provisional application(s) listed below:

\_\_\_\_\_  
(Application Serial No.)

\_\_\_\_\_  
(Filing Date)

\_\_\_\_\_  
(Application Serial No.)

\_\_\_\_\_  
(Filing Date)

\_\_\_\_\_  
(Application Serial No.)

\_\_\_\_\_  
(Filing Date)

I hereby claim the benefit under 35 U. S. C. Section 120 of any United States application(s), or Section 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. Section 112, I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, C. F. R., Section 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application:

\_\_\_\_\_  
(Application Serial No.)

\_\_\_\_\_  
(Filing Date)

\_\_\_\_\_  
(Status)  
(patented, pending, abandoned)

\_\_\_\_\_  
(Application Serial No.)

\_\_\_\_\_  
(Filing Date)

\_\_\_\_\_  
(Status)  
(patented, pending, abandoned)

\_\_\_\_\_  
(Application Serial No.)

\_\_\_\_\_  
(Filing Date)

\_\_\_\_\_  
(Status)  
(patented, pending, abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. (list name and registration number)

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